Near real-time coordinate estimation from double-difference GNSS data

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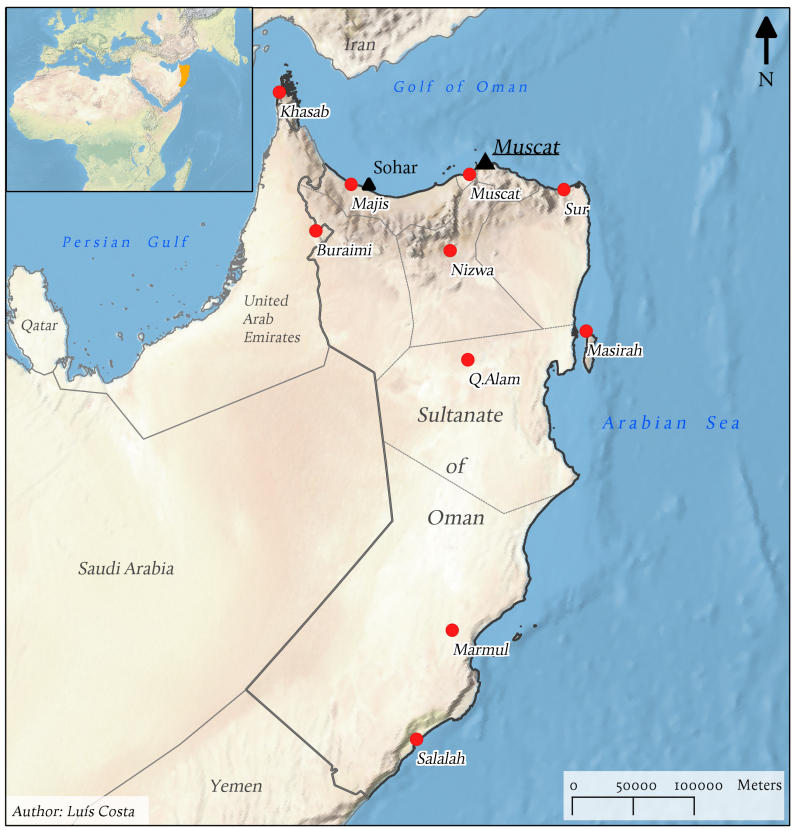
Near real-time GNSS data processing

- Wide range of important applications: Hazard monitoring, atmospheric sensing, network monitoring...
- Typical approach is based on a Precise Point Positioning (PPP)
- Advantages of PPP:
  - GNSS stations can be processed independently
  - Efficient method to process many stations $\rightarrow$ parallelize
- Disadvantages of PPP:
  - Accuracy of derived results mainly depends on the quality of used satellite clock estimates and consistency w.r.t. external network solution providing the satellite clocks
  - Ambiguity resolution (AR) becomes much more involved
- Potential of classical double-difference approach for near real-time applications

National Multi-Hazard Early Warning System

SpaceTech GmbH provides the GPS reference stations for the establishment of an early warning system in the Sultanate of Oman, in cooperation with GFZ Potsdam and AIUB.



- Seismic stations, GPS stations, meteo stations, tide gauges
- GPS network: 10 permanent stations. Cross-validate possibility of a tsunami after earthquake > 5 on Richter scale
- Requirement: Obtain displacement vectors within less than 2 minutes.

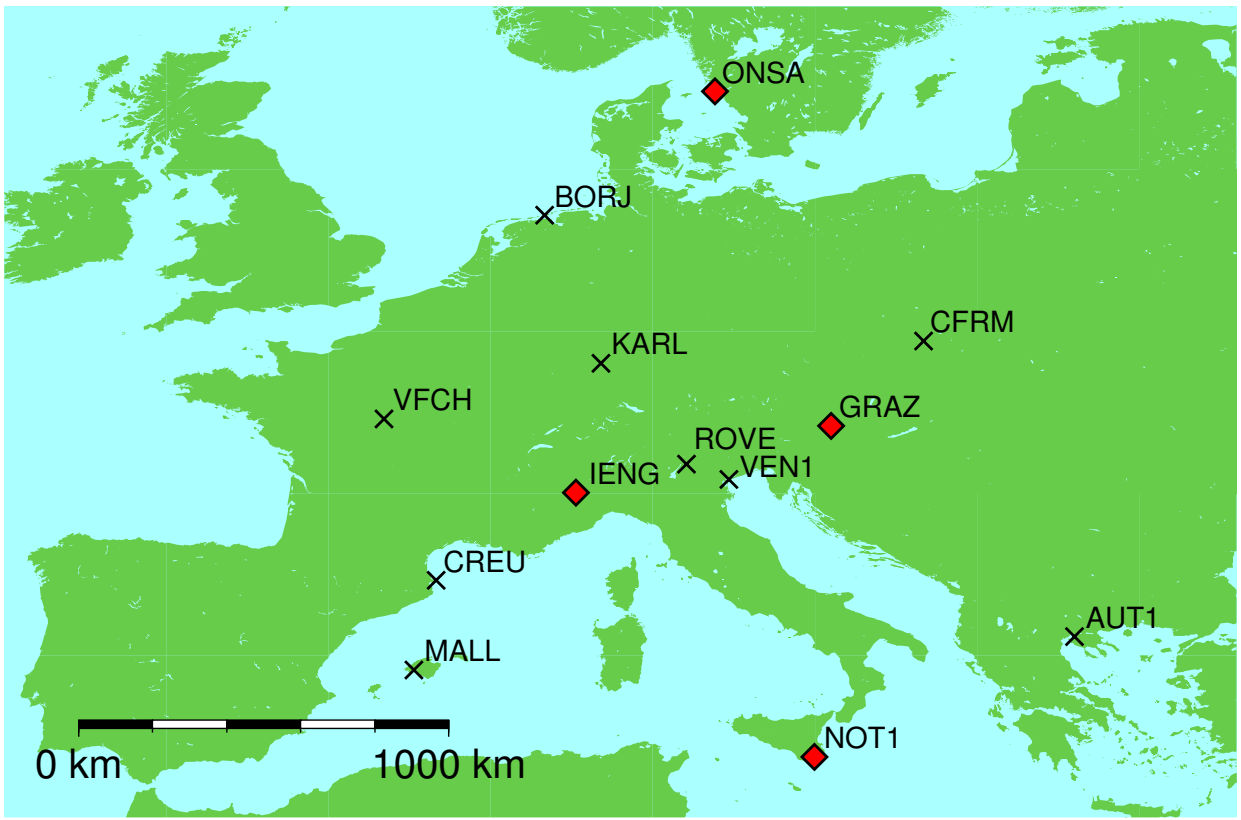
Test setup

To simulate the task of the GPS network in the early warning system, the following test environment was established:

- Warning stations: 9 European Permanent Network (EPN) stations providing real-time data, 1 s RINEX observation files streamed using BKG Ntrip Client (BNC).
- Reference stations: 4 IGb08 stations, 30 s hourly RINEX files dowloaded from FTP server.
- Rapid and ultra-rapid products from Center for Orbit Determination in Europe (CODE).
- Bernese GNSS Software v5.2.
- Server: 8 core Intel XEON E5-2660 2.2 GHz, 32 GB DDR3 memory.

Test setup

Geographical distribution of the stations:



×: EPN stations

◆: IGb08 stations

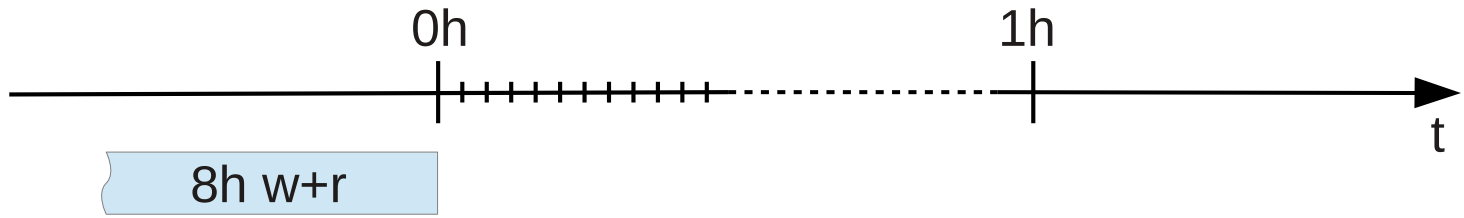
Processing strategy

The processing is divided into two main steps:

1. **Datum** (once per hour): Estimate static coordinates of warning and reference stations using a double-difference solution with extended ambiguity resolution (AR) procedure for different baseline lengths:
   - Code- and phase-based wide-lane AR
   - Code- and phase-based narrow-lane AR
   - Quasi-Ionosphere-Free (QIF) AR
   - Direct L1/L2 AR

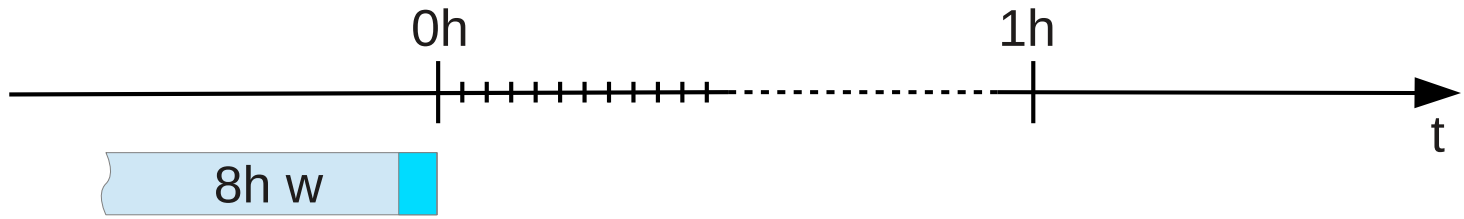
   Use (e.g.) 8 hours of data. Yields a priori coordinates for step 2.
2. **Near real-time** (every 2'): Estimate kinematic coordinates of warning stations only, using a double-difference solution with QIF AR. Use (e.g.) 8 hours of data for AR and the last 3 minutes for kinematic coordinates.

Processing strategy



w: warning stations, r: reference stations

Processing strategy



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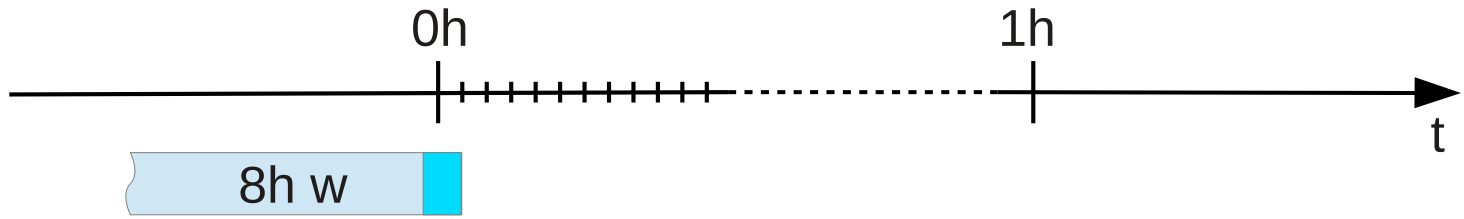

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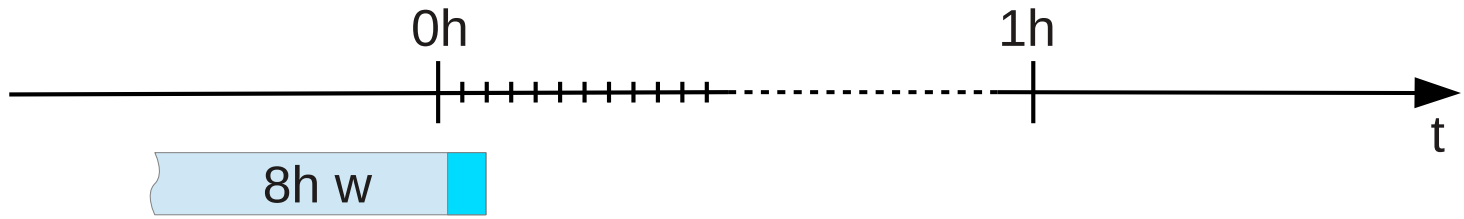

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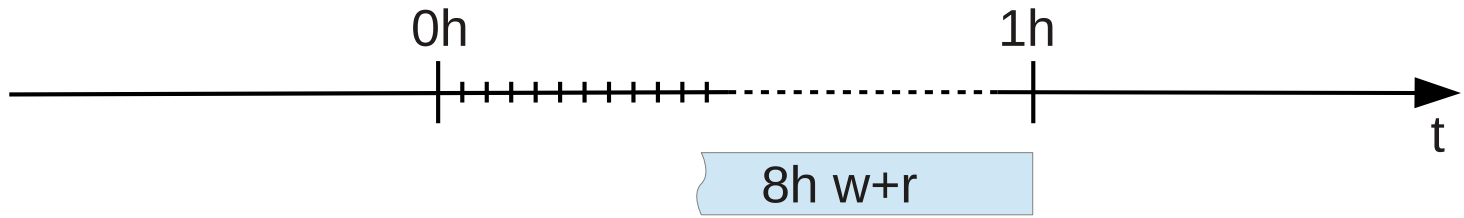

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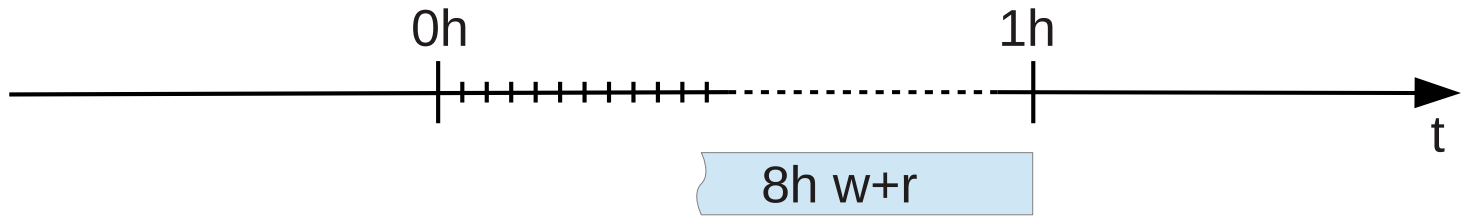
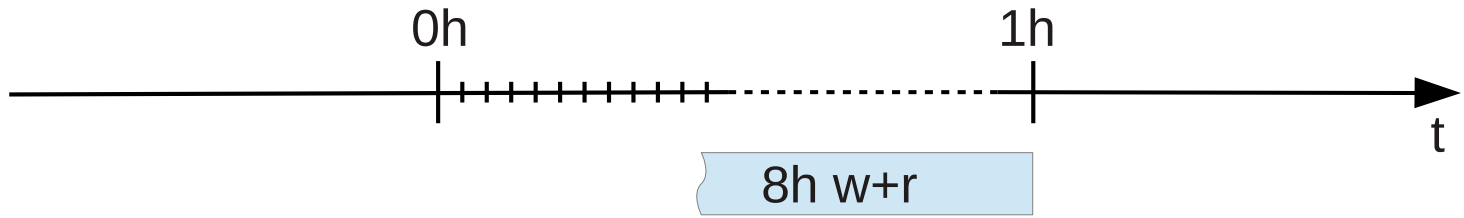


w: warning stations, r: reference stations

Comments:

- Reason for split-up into 2 steps:
  - Not many reference stations → long baselines → extended AR strategies (wide-lane, Melbourne-Wübbena + narrow-lane).
  - Reference stations would need to provide real-time data.

Processing strategy



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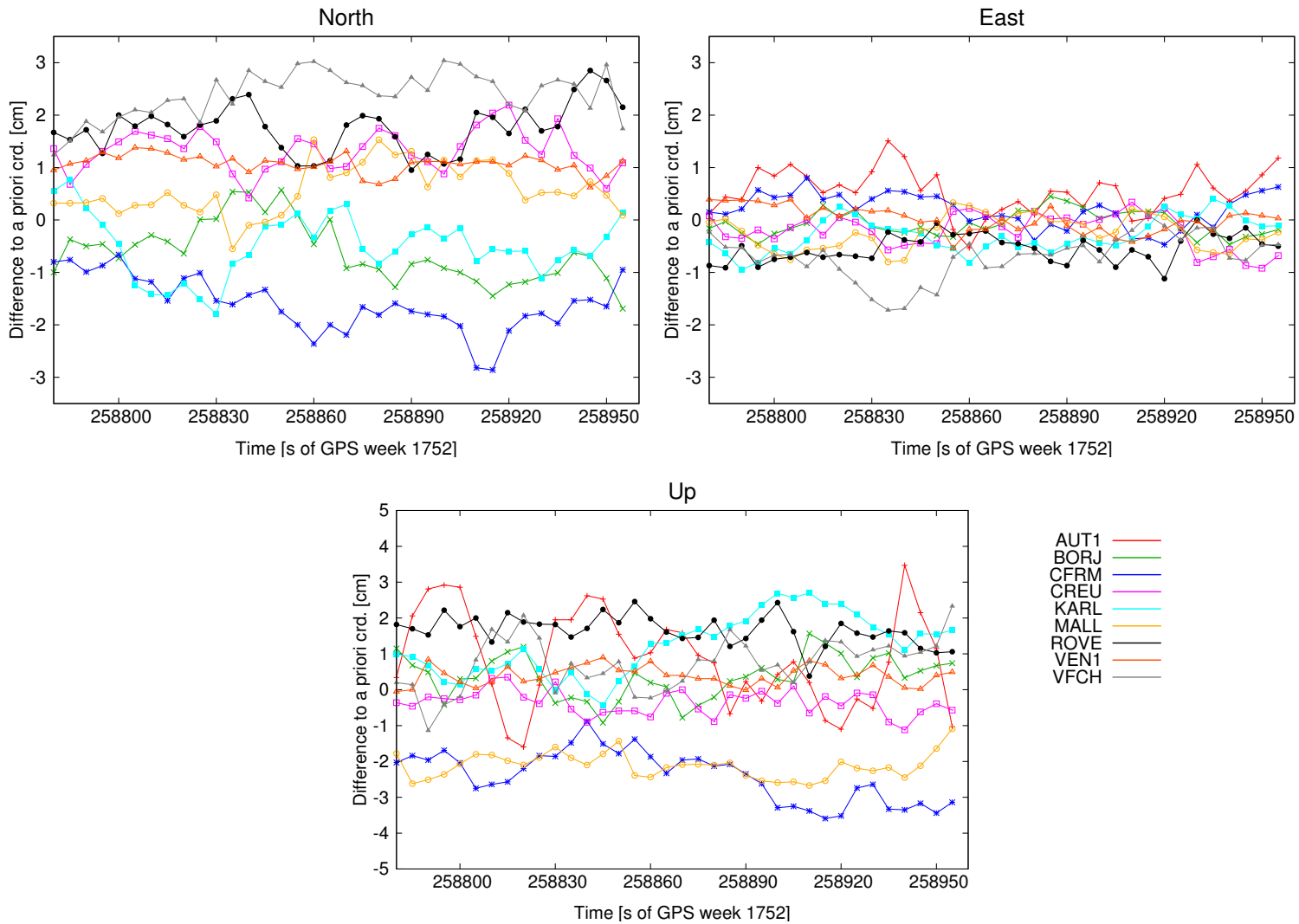
Comments:

- Reason for split-up into 2 steps:
  - Not many reference stations → long baselines → extended AR strategies (wide-lane, Melbourne-Wübbena + narrow-lane).
  - Reference stations would need to provide real-time data.
- (Pre)processing is consequently parallelized: 2 inversions of the full normal equation system, otherwise station by station or baseline by baseline.

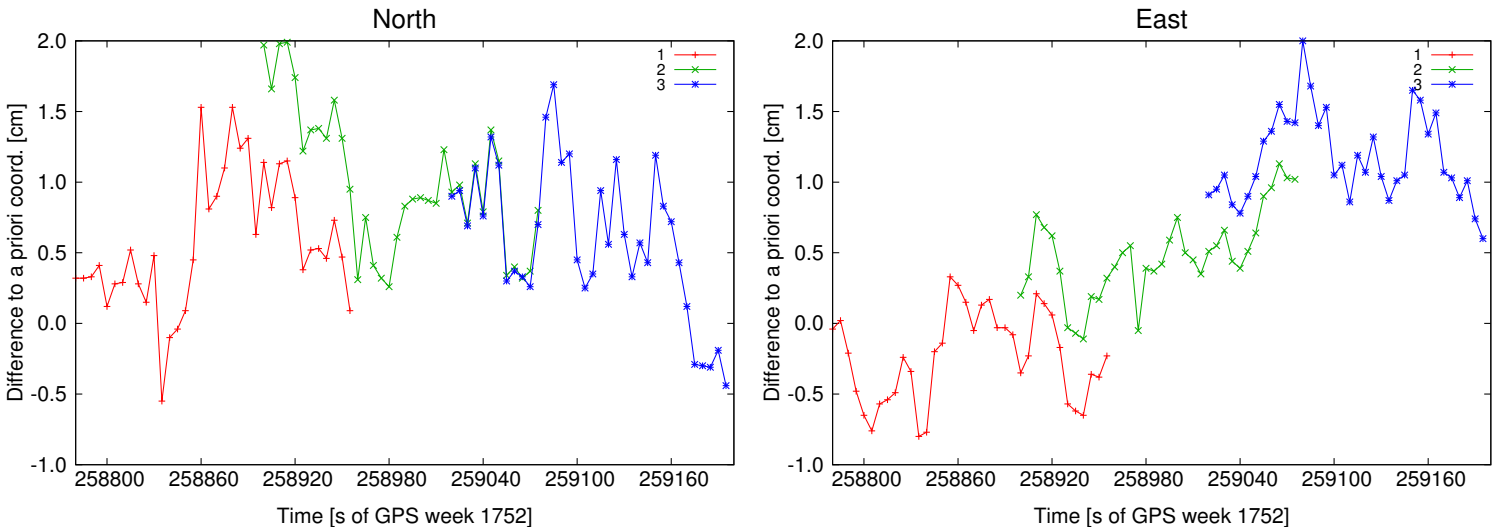
Kinematic coordinates

Kinematic coordinates (3 min), differences to a priori coordinates:



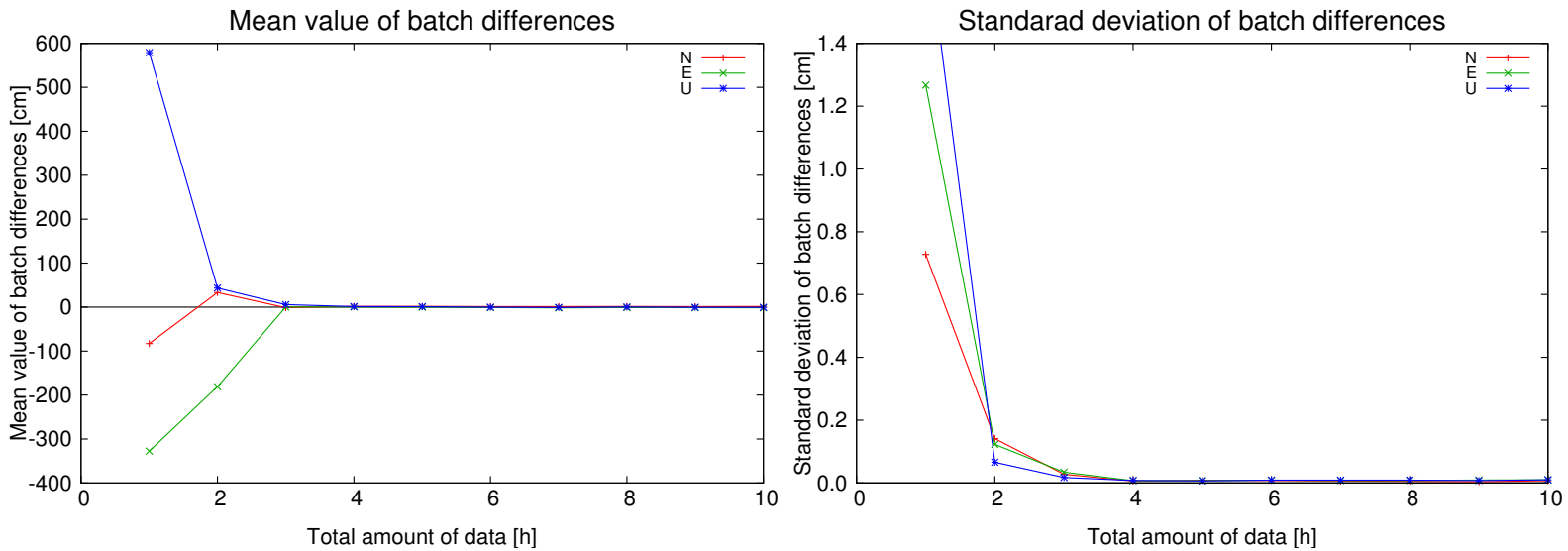
Kinematic coordinates

Overlaps of 3 min batches for one station (MALL):



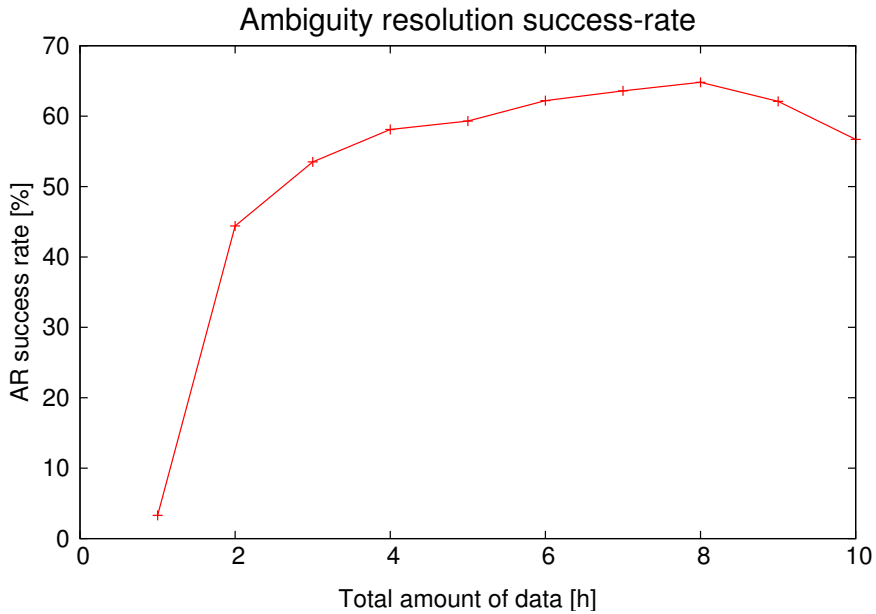
How much data?

Analyze overlaps of two consecutive 3 min batches (1 min overlap). Mean value and standard deviation of differences vs. total amount of data for one station (VFCH):



How much data?

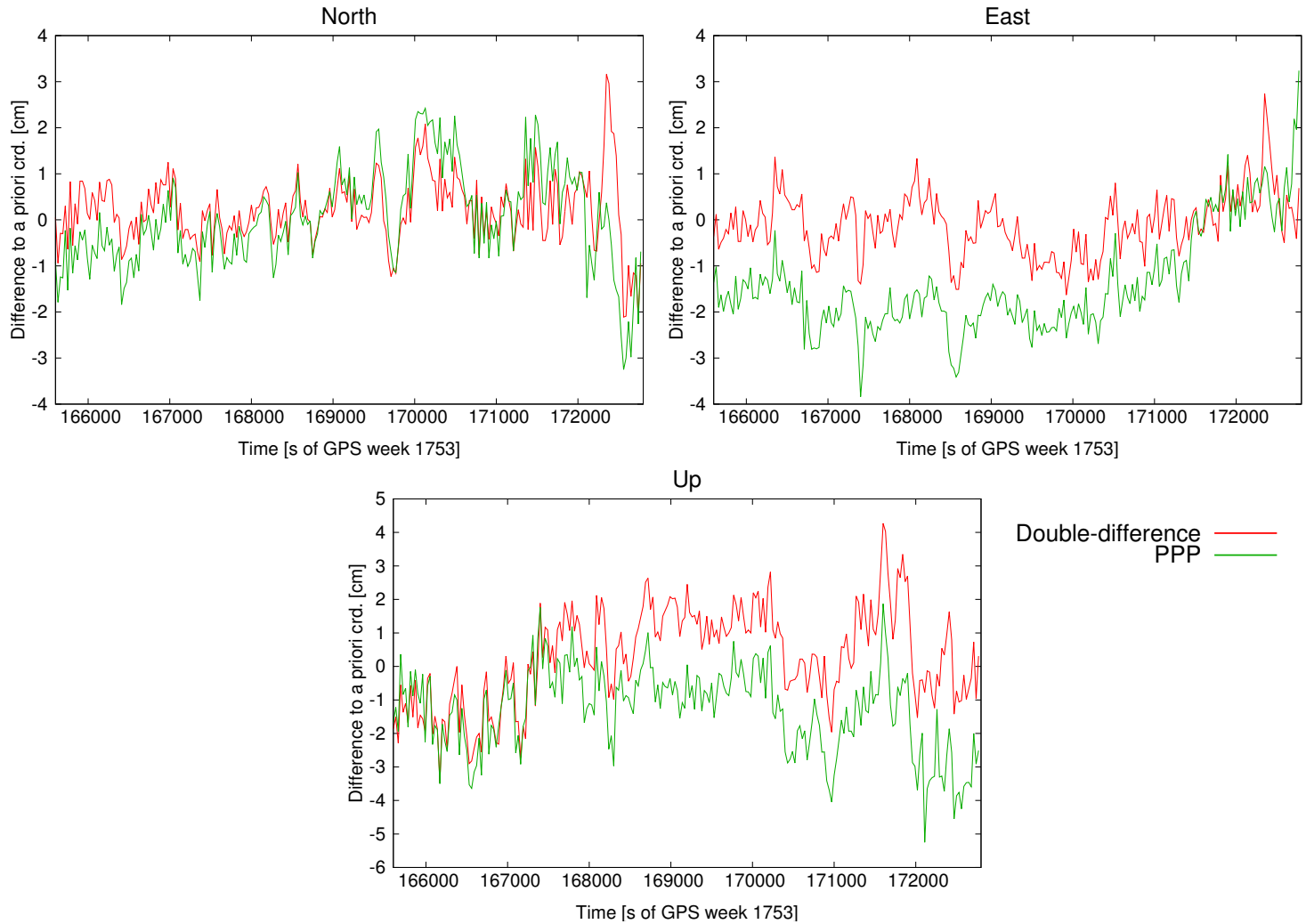
QIF ambiguity resolution success rate vs. total amount of data:



⇒ Enough data is needed for the processing, even if one is interested only in a few minutes of coordinates at the end!

PPP vs. double-difference

Comparison with results (2 h) of a PPP (rapid products of CODE, station KARL):



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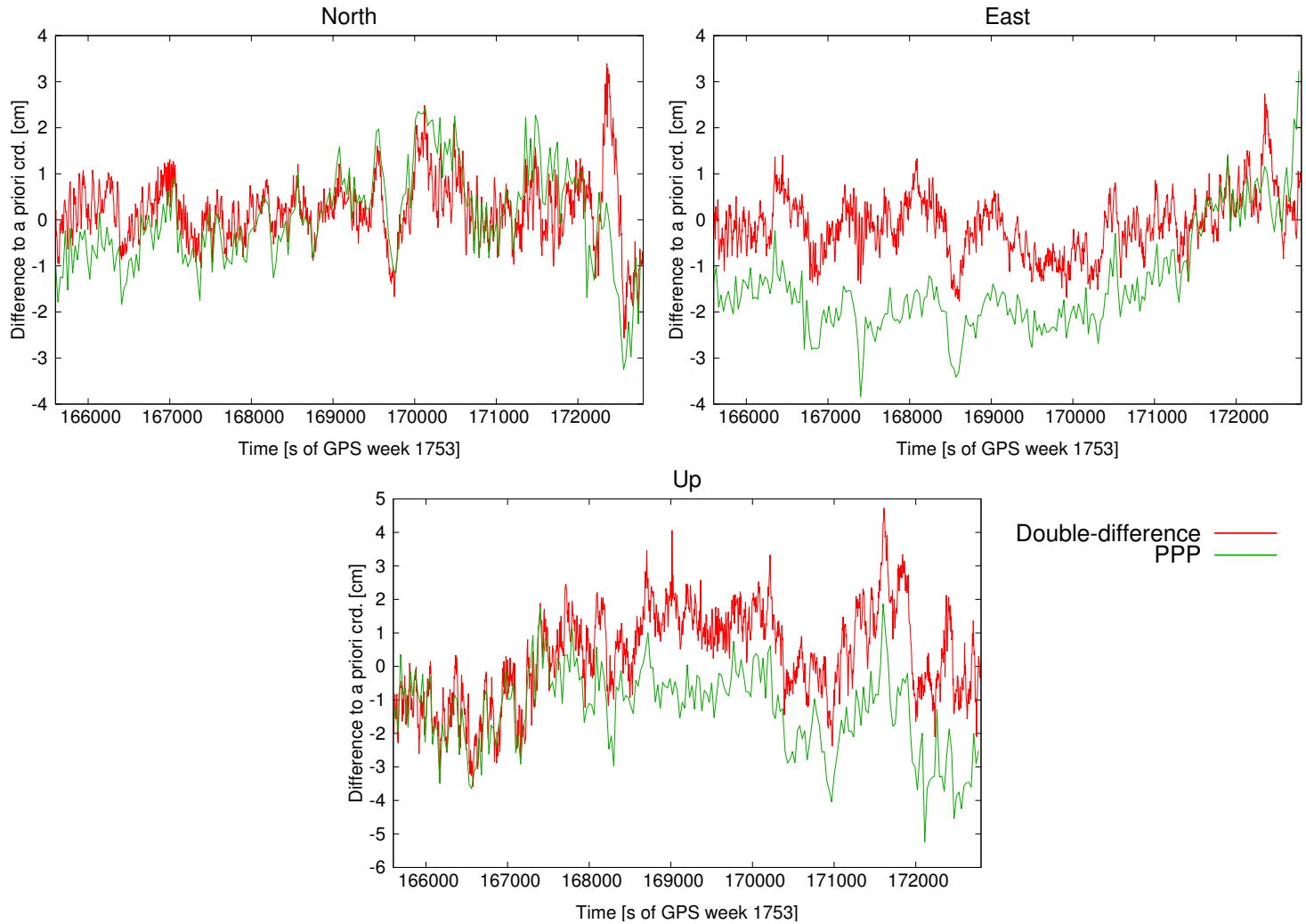

Conclusion

- Classical double-difference coordinate estimations can be well suited for near real-time applications.
- Independence of accurate satellite clocks. Higher sampling.
- There is a lot of potential for parallelization.
- Even if kinematic or static coordinates of only a few minutes are needed, an efficient ambiguity resolution needs enough data ($>$ 5 hours).